Radioisotope Applications Notes

This presentation addresses radioisotope sources and applications.

Slide 4 – U-238 decay chain graphic

- natural uranium abundant in Earth's crust and consists of two isotopes – U-235 and U-238
- both isotopes decay to stable isotope of lead as shown for U-238 decay chain
- in addition to U-235 and U-238, some decay chain isotopes long-lived and contribute to natural background radiation
- Th-232 also abundant in Earth's crust and decays to stable isotope of lead

Slide 5 – atmospheric C-14 production

- bombardment of Earth's upper atmosphere by cosmic rays produces energetic subatomic particles (secondary radiation)
- secondary radiation interacts with atomic nuclei in atmosphere to generate different nuclides (production of nuclides varies slightly with short-term variations in solar cosmic ray flux, but considered practically constant over long scales of thousands to millions of years)
- many so-called cosmogenic nuclides can be produced, but most notable is C-14, produced by interactions with nitrogen atoms (N-14 + n → C-14 + p + 0.626 MeV)
- C-14 eventually reaches Earth's surface where can be incorporated into living organisms
- C-14 has relatively long half-life and is plentiful in living organisms, but emits only low energy beta particle, so contributes very little to natural background radiation

Slide 6 – fission fragment mass distribution

- bi-modal distribution of radioactive fission fragments created when U-235 or Pu-239 fissions in nuclear reactors
- most probable fission fragments from U-235 fission have mass numbers of 95 and 137, each with less than 10% yield per fission event
- fission fragments and their decay products not released to environment and therefore do not contribute to background radiation

Slide 7 – particle accelerator

- aerial view of Fermi accelerator in Batavia, IL
- particle accelerators used to create variety of radioactive isotopes

- isotopes created in particle accelerators not released to environment and therefore do not contribute to background radiation

Slide 8 – nuclear weapon tests

- nuclear weapon testing ceased in accordance with Comprehensive Nuclear-Test-Ban Treaty of 1996
- some long-lived radioactive isotopes from nuclear weapon testing still exist in environment, but so dilute as to be of no health consequence

Slide 10 – radioisotope applications (cont.)

- in neutron activation analysis neutron source used to create radioactive isotopes of chemical elements in materials to identify chemical composition of the material

Slide 13 – nuclear medicine applications

- many radioisotopes used in nuclear medicine for diagnostic imaging as well as for treatment of cancer and other diseases
- ionizing radiation less invasive than surgery; has fewer, more localized (less severe) side effects than chemotherapy
- diagnostic imaging enables measurement and monitoring of various biological processes

Slide 14 – nuclear medicine radiation dose ranges

- graphic illustrates difference between diagnostic imaging radiation dose and cancer therapy radiation dose
- note that lower end of therapy dose more than 100 times higher than upper end of diagnostic imaging dose
- no evidence of adverse health consequences, much less cancer risk, from diagnostic radiation imaging dose

Slide 16 – thyroid scan using radioactive iodine

- radiotracer of I-131 given to patient orally
- probe measures amount of iodine uptake by thyroid gland
- scan checks distribution of radioactive tracer in gland to enable diagnosis of variety of thyroid gland disorders and diseases
- scans in upper right of graphic show normal thyroid and thyroid diagnosed with Graves disease

Slide 17 – CT scan of abdomen graphic

- Computed Tomography – medical imaging procedure that uses computer-processed x-rays to produce tomographic images, or “slices,” of specific areas of body

Slide 18 – PET scan of brain graphic

- Positron Emission Tomography – nuclear medicine imaging procedure that measures metabolic activity of cells and produces color-coded image of body’s function, rather than structure

- used primarily to evaluate people with cancer, brain diseases, and cardiac illnesses
- medical imaging technique utilizes annihilation radiation from positron interaction with electron that produces two gamma rays with equal energy (511 keV) traveling in opposite directions

Slide 19 – types of radiation therapy

- external beam radiotherapy most common type of radiation therapy used for cancer treatment
- external beam radiation given most often as photon (x-ray) beams and less often as particle (proton, neutron) or electron beams
- radiotherapy machines focus radiation beam on exact location in such a way as to maximize radiation reaching cancer, while minimizing damage to normal tissue
- most patients get fractionated therapy treatments over many weeks to permit recovery of nearby normal tissue via body's adaptive repair mechanisms
  - fractionated doses generally in the 200-300 rem range per treatment
- lacking normal cell repair mechanisms, tumor cells destroyed from cumulative exposures

Slide 20 – types of radiation therapy (cont.)

- brachytherapy type of internal radiation therapy that places radioactive seeds, ribbons, or capsules in or very near tumor
- results in higher doses of radiation being delivered to more-specific areas of body compared to external beam radiation therapy
- very effective in treating cancer as radiation delivered with high degree of accuracy; minimal risk of side effects due to targeted and precise nature of delivering radiotherapy from inside the body

Slide 21 – types of radiation therapy (cont.)

- slide shows size of brachytherapy seed implants

Slide 27 – non-destructive examination

- non-destructive testing/examination very important industrial application of radioisotopes for detecting internal flaws in materials that could compromise material integrity

Slide 28 – non-destructive examination (cont.)

- weld inspections important NDE procedure

Slide 29 – cargo scanning

- cargo scanning or non-intrusive inspection (NII) is non-destructive method of inspecting and identifying goods in transportation systems
- uses x-ray, gamma-ray, and neutron scanners to inspect cargo for threats like weapons, narcotics, or contraband without requiring cargo to be unloaded

Slide 30 – radiation sterilization

- relies on ionizing radiation**,** primarily gamma, X-ray or electron radiation, to destroy microorganisms such as bacteria, fungi, viruses and spores
- due to numerous advantages over heat- or chemical-based sterilization techniques, this method particularly attractive in medicine and healthcare-related fields (does not contaminate or damage consumer products)

Slide 32 – food irradiation

- radiation deposits energy in food products sufficient to kill microbes and bacteria
- ionizing radiation only interacts with electrons of atoms
- since radiation has no effect on proton/neutron composition of atomic nuclei, <u>cannot</u> make food or anything else radioactive
- can significantly extend shelf life of perishable foods

Slide 33 – environmental applications

- radioisotopes commonly used as tracers in environmental studies
  - — tracers are chemical compounds in which one or more atoms have been replaced by a radioisotope

Slide 36 – radiometric dating

- radiometric dating is common activity in environmental sciences
- C-14, K-40, Rb-87, and natural uranium dating among best known techniques for establishing geologic age of fossils, archeological materials, and rock formations
  - — half-life of 5,730 years makes C-14 useful for dating matter up to 30,000 years old
  - — extremely long half-lives of K-40, Rb-87, and natural uranium isotopes make them useful for dating matter up to age of Earth

Slide 37 – radiometric dating (cont.)

- if original amount of radioisotope in material is known, age of material determined from radioisotope half-life and amount of remaining radioisotope

Slide 38 – radiometric dating (cont.)

- slide shows radiocarbon dating process
- C-14 incorporated into all carbon-based lifeforms

- when lifeform dies, amount of stable C-12 remains constant while radioactive C-14 isotope decays with a 5730 year half-life to nitrogen
- C-14/C-12 ratio, which changes over time at known rate, used to determine age of biological material

Slide 40 – space applications (RTG)

- radioisotope thermoelectric generator (RTG) a type of nuclear battery that uses array of thermocouples to convert heat released by decay of suitable radioactive material into electricity
- RTGs powered by plutonium-238, with 87.7-year half-life, used as power sources in satellites and space probes

Slide 41 – nuclear batteries

- graphic shows other radioisotopes that may have potential use in nuclear batteries
- graphic is log-log plot showing energy density vs power density for nuclear batteries (red), chemical batteries (blue), fuel cells (green), and supercapacitors (gray)
- diagonal lines indicate relative duration of power output for capacitors, batteries and fuel cells and relative half-lives for the radioisotopes (between 2.6 and 433 years)
- for radioisotopes shown in graphic, Pu-238 has most desirable combination of specific activity (radioactivity per unit mass) and specific power (power per unit mass)